DESIGN OF A HYDRO ELECTRIC POWER PLANT ON THE BLACK RIVER AT HATFIELD WISCONSIN

by

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A Thesis Submitted

for the Degree of

BACHELOR OF SCIENCE

CIVIL ENGINEERING COURSE

UNIVERSITY OF WISCONSIN

1909

LOCATION OF THE RIVER

The Black River rises in Taylor County, a short distance above the City of Medford, Wisconsin, and flows in a southwesterly direction emptying into the Mississippi River near the city of La Crosse, Wisconsin.

The U. S. Geological Survey has made an accurate survey of this river from Black River Falls to Withee and the various locations for power purposes have been fully investigated.

Topography

The Black River lies in a long narrow valley between the Chippewa and the Wisconsin River valleys. The area of the watershed is about 2250 square miles with an average width of 20 miles. The lower course of this river is in a level sandstone valley, and power development is practically impossible as the gradient of the river at this place is about 2.2 feet per mile. The portion of the river above Black River Falls has a gradient of about 9 feet per mile with numerous falls and rapids. The banks are steep and the valley is very narrow, offering good facilities for pondage without overflowing too much land.

The total fall in a length of 140 miles is about 772 feet as is shown by the Profile Map. The steep gradient and narrow valley offer ideal conditions for power purposes but the narrowness of the watershed limits the quantity of water available.

Geology

The portion of the Black River under consideration lies in what is known as the Precambrian Rock covered, in some places, by Glacial Drift. The valley is comparatively young as the banks of the river rise in some instances to a height of 60 feet. Between Black River Falls and its mouth the river flows in the Potsdam Sandstone. Thru this part of the course the valleys have been widened and the banks are usually low.

Investigation of the Project

The investigation of the development of the water power project includes a sufficient and satisfactory examination of every factor that in any way affects the head available and the discharge of the river at the proposed location of the power plant. A fairly accurate knowledge of the conditions existing upon the stream at the present time can be had from surveys and river gage observations. However, the conditions existing upon a river are constantly changing, and it is this cause and rate of change that most affects the factors of available head and stream flow. While a knowledge of existing conditions is essential and necessary, it is the variations from the present conditions that may occur that furnishes the most valuable information.

Extent of Investigation

The investigation of the power which can be utilized

consists in a most careful determination of:-

First:- The head available

Second:- The stream flow

Head Available

Topographical conditions affect, to a large extent, the height of fall which may be utilized by the construction of a dam. The flood height in the river valley above limits the practicable height of the dam. An available head of 50 feet can be utilized at the point of development under normal conditions of flow. During high water periods the head will be considerably reduced due to the backing up of the tail water.

Runoff

It is of the utmost importance that there be obtained information covering the entire range of variations in rainfall, temperature, barometric pressure, and other modifying factors. This necessitates actual daily observations on the stream in question for a sufficient number of years to include this range of variations.

Observations on the Black River have not been conducted for a period of years great enough to give this information. Consequently, resort must be had to neighboring rivers whose drainage areas possess similar physical and meteorological features, and regarding which more adequate data on stream flow is available.

In considering the geographical location of the Black

River watershed it is found that a comparative study of the discharges of the Wisconsin River at Merrill and of the Chippewa River at Eau Claire will furnish information next in importance to that existing on the Black River itself.

From the Location Map it is seen that the areas of these three watersheds are adjacent. The proximity of these drainage basins insures reasonable similarity of climatic conditions such as rainfall, temperature and barometric pressure. Marked similarity is found in their geological and topographical features as investigated from geological maps. It is, then, permissible to draw conclusions as to the flow which would have probably occurred on the Black River from data obtained on these other rivers. From the best available state maps the drainage areas of the three rivers have been carefully measured. For the purposes of this investigation the flow may be considered proportional to the areas of the watersheds. This is not strictly true. Small drainage areas show the effects of heavy rains by an immediate and large increase in the flow, while the discharge of large streams is more modified by the fact that heavy rains seldom obtain all over a large area and the time required for the run-off to reach the main stream is correspondingly greater.

Rainfall

A study of the relation of annual rainfall and runoff is essential, since the discharge of the stream is corres-

pondingly affected. However, no exact relation existing between rainfall on a drainage basin and stream flow can be traced out, because of the variations in the periodic distribution of the annual rainfall. A small total annual rainfall might be so distributed as to cause a greater stream flow thana larger rainfall more uniformly distributed thruout the year. Considerable rainfall data covering a long period of years, gives a fair basis for estimating the probable stream flow for such years for which no run-off data is at hand.

A better understanding of the relation of rainfall to runoff may be had by referring to the water year instead of the calendar year. The water year naturally divides itself into three periods, beginning with December and ending with the following November. The first or storage period begins with December and ends with the following May. June, July, and August are termed the growing period and the third or replenishing period extends thru September, October, a nd November. This artificial division into calendar months is only approximate and the periods vary from year to year.

The storage period extends over the winter and early spring months when the ground is saturated from the winter snows and spring rains and a large amount of water is held in storage in the swamps, lakes, forasts,and in pervious soils, sands, and gravels. Precipitation received upon

frozen or saturated soil is almost immediately and entirely delivered in the form of runoff. During the storage period the stream flow will be quite irregular due to the fluctuations in the rainfall, and in April or May maximum flood conditions will obtain due to the melting winter snow and spring rains.

Except during unusually heavy storms the stream flow thruout the growing period is entirely dependent upon the ground water. This is due to the fact that during June, July, and August the rainfall is rarely sufficient to take care of the evaporation and growth of vegetation.

By the end of the growing period much of the ground water has been drawn upon and is so reduced as to be capable of storing several inches of rainfall.

During the replenishing period the ground begins to renew its store of water and most of the rain falling at this time is absorbed, except during unusually heavy storms of short duration.

Comparative Flow

"Other things being equal it is evident that the quantity of water flowing from each square mile of a drainage area in a given time should be essentially the same, and while this may not be true for a given day of a particular year, yet on the drainage area of the same river where the conditions are essentially similar, this law of flow will be found to hold for average conditions. If, therefore,

the flow as found by observations at the gaging station at Neilllsville is reduced in the proportion that the drainage area above the other stations bears to the drainage area at Neillsville, the flows so reduced may be regarded as representing, with reasonable accuracy, the flows which occurred during the same periods at Neillsville; and in turn this flow can be reduced to that at Hatfield where no gagings were taken. All hydrographs in this report therefore have their flow reduced to the flow at Hatfield on the Black River.

On these diagrams the horizontal scale repeesents time and is subdivided into months, and from this scale any day in the year can be located. The vertical scale on these hydrographs pepresents stream flow in cubic feet per second per square mile of drainage area for each day. From any hydrograph therefore the flow at any station on the river; and for any day during the period of the observations can be approximately determined by reading the discharge in cubic feet per second per square mile and multiplying the flow so determined by the number of square miles of drainage area above the station. These hydrographs have also been prepared to show the actual horse power, corresponding to the actual stream flow, that might have been developed during this period at Hatfield if a sufficient installation of turbines had been available. The basis of this calculation is the power delivered by turbines of 80% efficiency under a head of 50 feet.

The power scale is placed at the right of the diagram and measures the available daily power in horse power hours. A horse power exerted continuously for one hour would represent a horse power hour equivalent to 1,980,000 foot-pounds of work. In the scale of power to the right of the hydrographs the figures represent the horse power hours per day of 24 hours each of continuous flow.

Power of the River

Since there is no gaging station at Hatfield all discharge measurements were calculated from the discharge at Neillsville, the discharge varying directly as the watershed areas. An examination of the profile of the Black River in the vicinity of Hatfield will show that a head of 50 feet is available exclusive of the drop required in the tail race. By erecting a 50 foot dam at this point an area of 1200 acres will be flooded, but this does not interfere with any developments, therefore a head of 50 feet will be used. This will be reduced to a head of 35 feet during high water, and at that stage will flood an area of 1000 acres. After some study of topography it is assumed that this flooded area between the 35 and the 50 foot heads varies by a constant increment. For each additional head of one foot the increased acreage will therefore be 13.3 acres.

From a study of the hydrographs a minimum flow of 170

cubic feet per second was determined. The plant is to be designed for a run of 10 hours each day. Therefore a considerable amount of water can be impounded during the night to increase this minimum flow. Assume impounding to continue for 12 hours daily. It will not be advisable to shut off the flow of the river entirely since riparian owners may object. Therefore we will assume a storage over night of 90 cubic feet per second, allowing 80 cubic feet per second to pass on down stream. This amount of water will raise the level of the reservoir at its lowest stage by the following amount:- 90 cubic feet per second for 12 hours equals 3,888,000 cubic feet of water. 1000 acres equals 43,560,000 square feet. This gives a rise of .9 feet over the surface, neglecting the additional fraction of the 13.3 acres flooded. The actual rise will be less than this. The total flow will be, then, 170 + 90 or 260 cubic feet per second.

If no pondage or storage is depended upon to alter the flow of the river it is evident that the continuous power obtainable must be based upon minimum flow values.

The following table has been made with a discharge of 170 cubic feet per second, the minimum flow, showing the variation of power with a head ranging from 35 to 50 feet.

Table One

Power of the Black River at Hatfield under various heads and at the minimum flow of 170 cubic feet per second which can be utilized by different daily periods of use.

Head	Continuous Horse Power	Total Horse Power Hours for 24 hours	15 hours	12 hours	10 hours
35	675	16200	10100	8100	6750
40	772	18500	11600	9250	7720
45	870	20900	13000	10450	8700
50	965	23200	14500	11600	9650

Pondage

In order to guard against a low flow and to avoid impounding at night, storage will be considered. The following table shows the storage for various heads and the power stored stored in same.

Table Two

Head	Acreage	Cubic feet Storage	Horse Power Hours
35	1000.0	0	0
36	1013.3	44,060,000	40,500
37	1026.6	44,560,000	42,500
38	1039.9	45,060,000	43,700
39	1053.2	45,560,000	46,500
40	1066.5	46,060,000	47,500
41	1079.8	46,560,000	48,500
42	1093.1	47,060,000	50,300
43	1106.4	47,560,000	52,500

Table Two (continued)

Head	Acreage	Cubic Feet Storage	Horse Power Hours
44	1119.7	48,060,000	54,500
45	1133.0	48,560,000	55,500
46	1146.3	49,060,000	57,500
47	1159.6	49,560,000	59,300
48	1172.9	50,060,000	60,500
49	1186.2	50,560,000	63,500

Storage capacity equals 724,800 horse power hours.

It is to be determined whether this pondage is sufficient to maintain a flow of 250 cubic feet per second over the period of minimum flow. The minimum average flow for a month on the Black River at Hatfield is 250 cubic feet per second for the months of July and August of the year, 1906. From the hydrographs this flow corresponds to a value of 28,800 horse power hours at 80% efficiency and at a head of 50 feet. Since the other monthly averages are much higher than the value above the power value might be raised by storage.

Assuming that we wished 30,000 horse power hours continuously from the dam, we would have to investigate the storage capacity to be sure we could raise our power to even this slightly greater amount. The capacity of the dam from the preceding table is seen to be 724,000 horse power hours at 100% efficiency, or 580,000 horse power

hours at 80% efficiency. Assuming that the month of July will require drawing the dam down from 50 feet to 44 feet with an average head of 47.5 feet, the amount of power due to average flow and 47.5 feet head will be 25,500 H. P. H. This value is less than the assumed value of 30,000 by an amount equal to the difference or 4,500 H. P. H. each day. This gives a monthly value of 135,000 H. P. H. to be taken from the pond. From the table it is seen that drawing the pond to 44 feet gives a value of 297,000 H. P. H. or a total of 238,000 H. P. H. at 80% efficiency. The difference between the amount available with this draw and the required amount is 103,000 horse power hours excess to be run over into the next month.

Proceeding in the same way with the month of August, we will assume the pond drawn down to 38 feet with an average head of 41 feet. With a flow of 250 cubic feet per second and a head of 41 feet a value of 22,400 H. P. H. at 80% efficiency is obtained. This is below the assumed value of 30,000 H. P. H. by the amount of 7,600 or a monthly value of 228,000 H. P. H. Drawing pond down to 38 feet gives a value of power equal to 300,800 H. P. H. or 246,000 H. P. H. at 80% efficiency. This plus the excess of 103,000 from July gives an available power of 349,000 horse power hours. The excess to be run over into the next month is 349,000 minus 228,000 or 121,000 horse power hours.

September has a value of average flow greater than 250 cubic feet per second but since it is utilized at a head of 37 feet instead of at 50 feet, it must be investigated to see if the available power reaches a value of 30,000 H. P. H. The average stream flow for the month of September is about 380 cubic feet per second, which, at 80% efficiency and under a head of 37 feet gives a power value of 31,000 horse power hours.

The pondage is thus seen to be sufficient for a much higher value than 30,000 horse power hours, but since only 25,000 are required for the installation as decided upon, the limiting value will not be calculated.

Design of Spillway

It is necessary to consider the portion of the dam required to pass the flow of large floods over the spillway. The maximum gage reading at Neillsville on June 5, 1905 was 19.5 feet, corresponding to a maximum discharge of 18,000 cubic feet per second, or to a maximum discharge of 30,000 cubic feet per second at Hatfield.

The topography of the river channel at the point of development requires that a dam 360 feet in length be constructed. The discharge will vary with the type of dam selected, owing to the coefficient of discharge varying. An Ogee type of dam will be used in which the coefficient will lie between 3.0 and 3.5

Assume a coefficient of 3. The discharge will vary according to the formula

$$Q = clh^{2/3} \qquad \text{in which}$$

Q = discharge in cubic feet per second

c = coefficient

l = length of spillway in feet

h = head on crest in feet

$$h = \left(\frac{Q}{cl}\right)^{2/3} = \left(\frac{30,000}{3 \quad 360}\right)^{2/3} = 9.2 \text{ feet}$$

The head on the dam therefore equals 9.2 feet.

Assume 3.5 for the coefficient of discharge. "h" is then computed to be 8.3 feet. In time of maximum floods the head on the dam will therefore lie between 8 and 9 feet. The total length of the dam must be used as spillway and this will necessitate building the plant on one end of the dam instead of in it as was first intended.

By moving the dam upstream a short distance the total length could be increased to about 500 feet, giving a head of 6.7 and 7.4 for the respective coefficients. The site of the 360 foot dam will be selected however.

DESIGN OF POWER PLANT

Factory and Load Cutves

The factory to which power will be furnished will use power at the rate shown on the Load Curve accompanying this discussion. It will be seen that the power used varies and it is well, therefore, to install such units as will give the greatest efficiency under the varying conditions of load.

The units should be small enough to allow a fair regulation of the amount of power. At the same time, the coat of a large number of small units is greater than the cost of a fewer number of large units, and the small units require more room to house them. The cost of operation and repairs on small units is also graater, but in case a unit is disabled a smaller one can more easily be spared. Units selected should be as uniform as possible so that fewer repairs need be kept on hand.

From the load diagram it will be seen that the maximum peak load is about 1800 kilowatts. The total capacity of the plant will be 18600 K. W. H. or 25,000 H. P. H. per day. Since the maximum peak load of 1800 K. W. or 2400 H. P. occurs but for a short time each day, we will recommend the installation of four units of 500 K. W. capacity each. These may be run at 25% overload for 2 hours to take care of the peak load.

For light load as occurs during the night or the

starting loads in the morning the number of units can be regulated to suit conditions.

To deliver 25,000 H. P. H. the equipment required would be as follows:

Hours of Use	Load Factor %	Machine Capacity H.P.	K.W.
24	100	1044	780
18	75	1395	1040
12	50	2088	1560
10	40	2500	1860
8	33	3120	2330

To deliver 37,000 H. P. H. as computed from the comparative hydrographs the following equipment would be reqd.

Hours of Use	Load Factor %	Machine Capacity H.P.	K.W.
24	100	1540	1150
18	75	2050	1530
12	50	3080	2560
10	40	3700	2760
8	33	4600	3420

The plant will be developed on a basis of 25,000 horse power hours. Four 500 K. W. Three Phase Alternating Current Generaters will be installed. The rated capacity of the four units will be 2000 K. W. Three alternators will provide a capacity of 1500 K. W., and at 25% overload will furnish 1875 K. W. Sufficient power will be provided by three units, leaving at the same time one unit in reserve.

Generators

The generators will consist of four 25 cycle, three phase alternators, each with a rated capacity of 500 K. W. These alternators will operate at 310 R. P. M. and are directly connected to turbines.

Excitors

The exciters will consist of two 100 K. W., 800 amp., 100 volt direct current generators operating at 600 R. P. M. and directly connected to turbines.

Selection of Turbine Units

It will require 2000 horse power to run the generators and 400 horse power to operate the exciters. A total of 300 horse power will be necessary to satisfactorally run each unit and the turbines must be so chosen to produce this power. The values of constants used in the formulae were taken from Prof. D. W. Mead's Water Power and from his Notes on Hydraulic Machinery. The turbines to operate efficiently under the existing conditions must be carefully selected. Catalogue conditions may be sufficiently accurate under a fixed head and flow but in case the head is a variable the turbine must be able to meet these conditions in order to operate efficiently.

Conditions existing at Hatfield:-

First- The head varies from 50 to 35 feet.

Second- The power required from each unit is 300 H. P.

Third- The generators are to run at approximately 300

Calculations

The relation of speed and power is given by formulae:

$$K_5 = \frac{N^2 P}{h^{5/2}}$$

K_5 varies directly with the power of the turbine. The installation includes four units and each unit consists of two turbines making a total of eight turbines. For each turbine

$$K_5 = \frac{300^2 \times 2500}{42^{5/2} \times 8} = 2000$$

Values of K_5	Minimum	Maximum
Alcotts Special High Duty Turbine	2152	2300
Chase-Jonval Regular	1680	2580
McCormick	2380	2862
Hercules	2030	2155
Victor Register Gate	2254	2712

The relation of power and diameter of various American Turbines is expressed by formula:

$$K_2 = \frac{P}{D^2 h^{3/2}}$$

Values of K_2	Minimum	Maximum
Alcotts Special High Duty Turbine	.000589	.000999
Chase-Jonval Regular	.00059	.00078
McCormick	.00168	.00171
Hercules	.00147	.00159
Victor Register Gate	[illegible]	[illegible]

Tests of the actual operating conditions have been made on several series of wheels. These tests were made under certain definite conditions and the test of each wheel installed is practically impossible. The following conditions or relations exist between wheels of a homogeneous series but operating under different head, r.p.m., diam. etc.

D = Diameter in inches

Q = Discharge in cubic feet per second

H = Head in feet

N = Number of revolutions per minute

P = Horse power

$$\frac{D}{D_1} = \frac{P^2}{P_1^2}$$

$$\frac{Q}{Q_1} = \frac{D^2}{D_1^2}$$

$$\frac{Q}{Q_1} = \frac{h^{1/2}}{h_1^{1/2}}$$

$$\frac{P}{P_1} = \frac{h^{3/2}}{h_1^{3/2}}$$

$$\frac{n}{n_1} = \frac{h^{1/2}}{h_1^{1/2}}$$

Knowing the operating conditions of a wheel of any size

under any head, the conditions of operation of a homogeneous wheel of the same make but of different size, and operating under a different head can be computed.

Two wheels of the above series were considered.

First- McCormick Turbine. Wellman Seaver Morgan Co.
Test Record on page 717, Mead's "Water Power"
Diameter of turbine tested 39 inches
Diameter reduced to 26 inches

Second- Chase Jonval Turbine. Chase Turbine Mfg. Co.
Test Record on page 725, Mead's "Water Power"
Diameter of turbine tested 30 inches
Diameter increased to 36 inches

The Chase Jonval Turbine was found to give low efficiency at part gate opening as is shown by the accompanying characteristic curve.

The McCormick Turbine gave fair values of efficiency at part gate opening and under varying head. The horse power which the turbine is capable of delivering ranges from 260 at 35 foot head to 350 under a head of 50 feet. The head at which the wheels will operate most of the time will range from 40 to 45 feet. At three-fourths gate and under a head of 42 feet the turbine will deliver 310 horse power.

Characteristic Curves

The characteristic curve is drawn to make a more thorough analysis of a wheel, based upon a test that can be deduced from catalogue conditions.

Notation used:

v' = velocity of periphery of impeller, feet per second

v = theoretical spouting velocity due to head

ϕ = ratio of v' to v

n = revolutions per minute

h = head in feet

THP = theoretical horse power

AHP = actual horse power

$$\phi = \frac{v'}{v} = .000543 \frac{Dn}{h^{\frac{1}{2}}}$$

The diagram is plotted with values of ϕ and R. P. M. under one foot head as ordinates, and discharge in cubic feet per second as abscissae. The points are platted and the efficiency as determined by the test is printed near the point. Efficiency lines are then drawn thru points of equal efficiency.

A. H. P. = T. H. P. × Efficiency

The actual horse power is known for each point from the test and these values are also printed near the platted points. A. H. P. lines similar to efficiency lines are then drawn and from these a scale of T. H. P. at 100% efficiency is placed on the upper margin of the diagram. The deductions are made from the relations previously shown.

The accompanying graphical analysis shows the operation of the McCormick Turbine under a one foot head. These

values were deduced from the test of a 39 inch McCormick Turbine operating under an approximate average head of 15 feet. In these curves the following values under one foot head and various gate openings are platted.

Ordinates	Efficiency
	Actual horse power
	Discharge
Abscissae	Revo. per minute

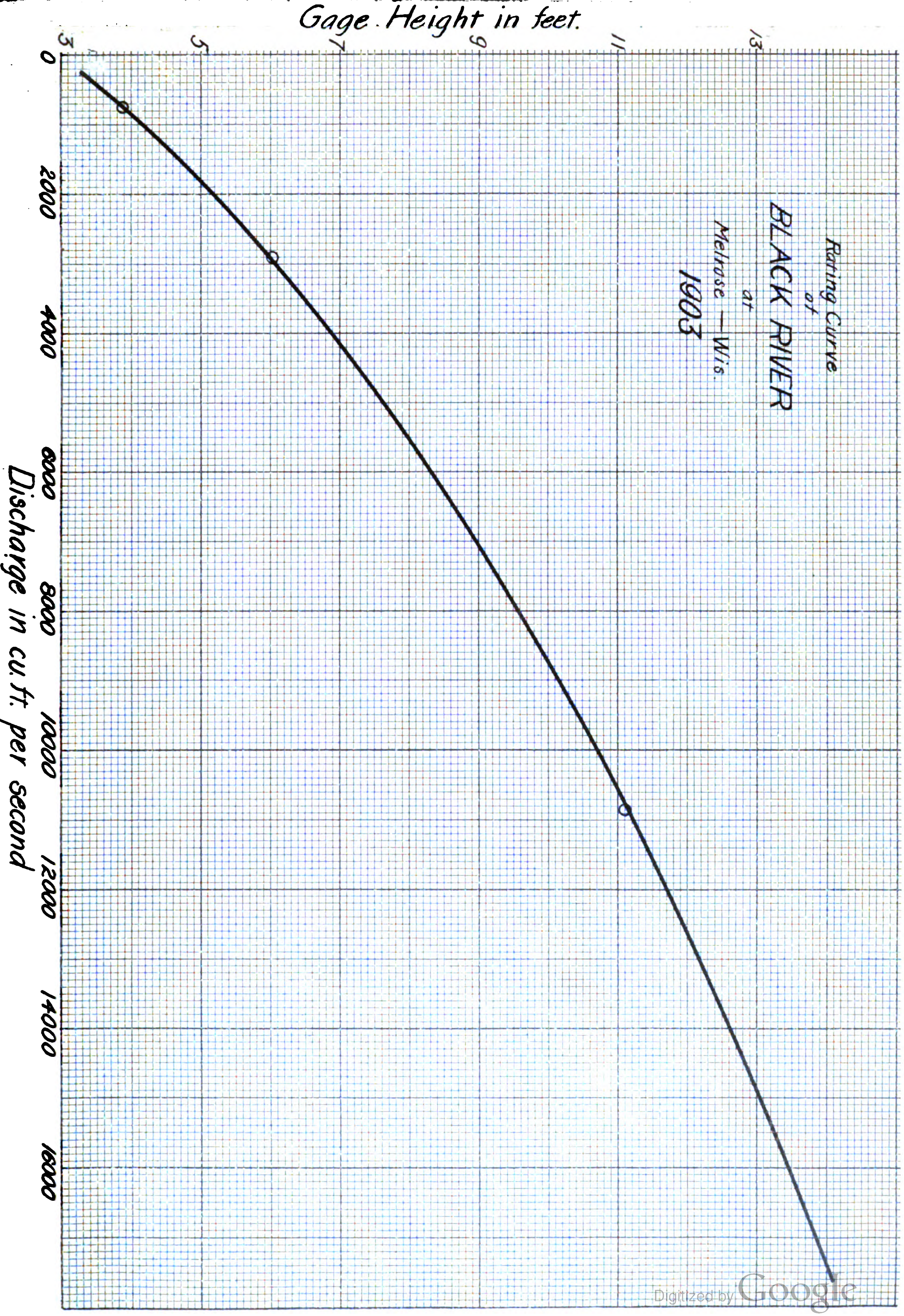
For the same wheel at 310 revolutions per minute and under 35 and 50 foot heads the equivalent speed is determined by the equation

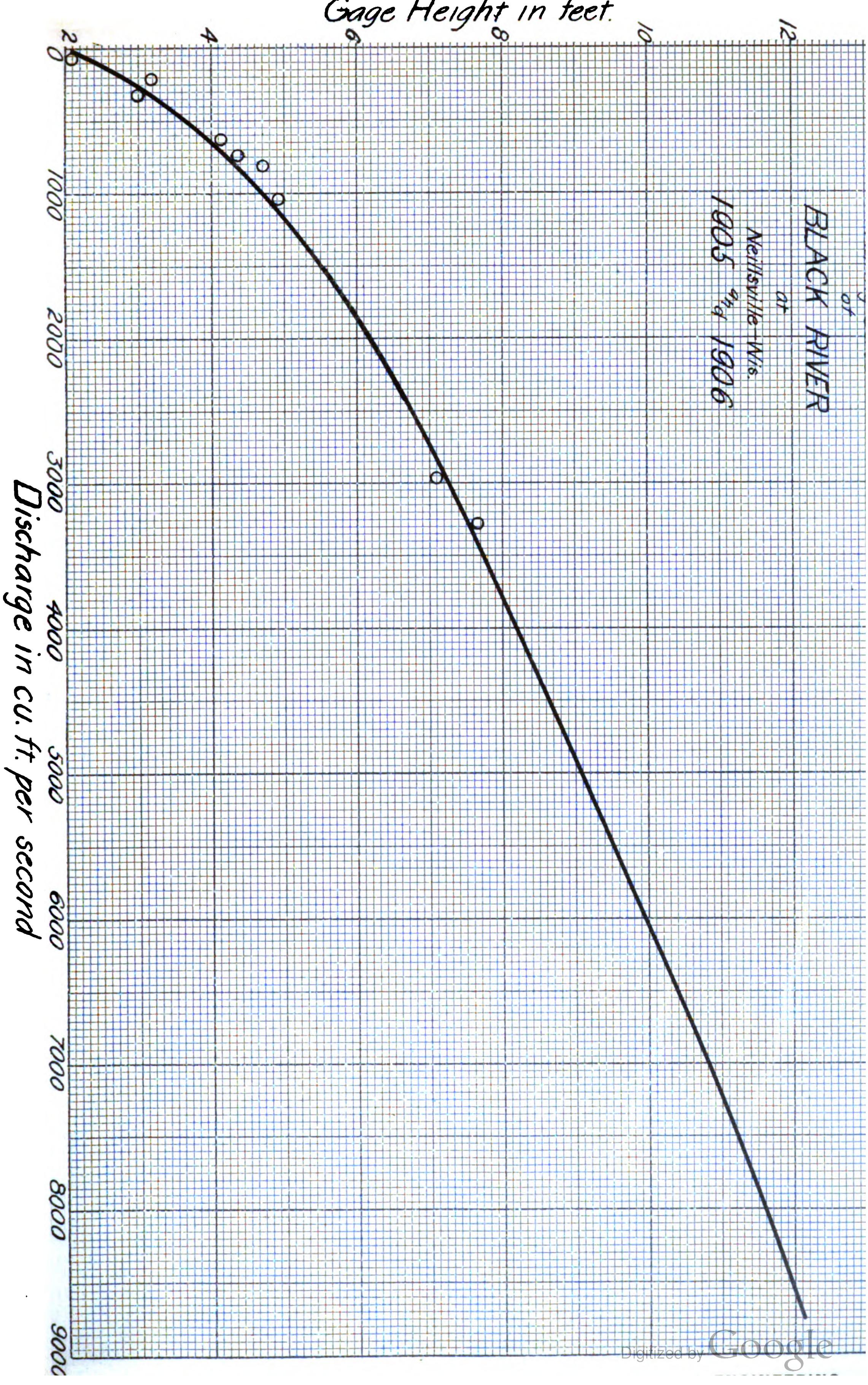
$$\frac{n}{h^{\frac{1}{2}}} = \frac{n_1}{h_1^{\frac{1}{2}}}$$

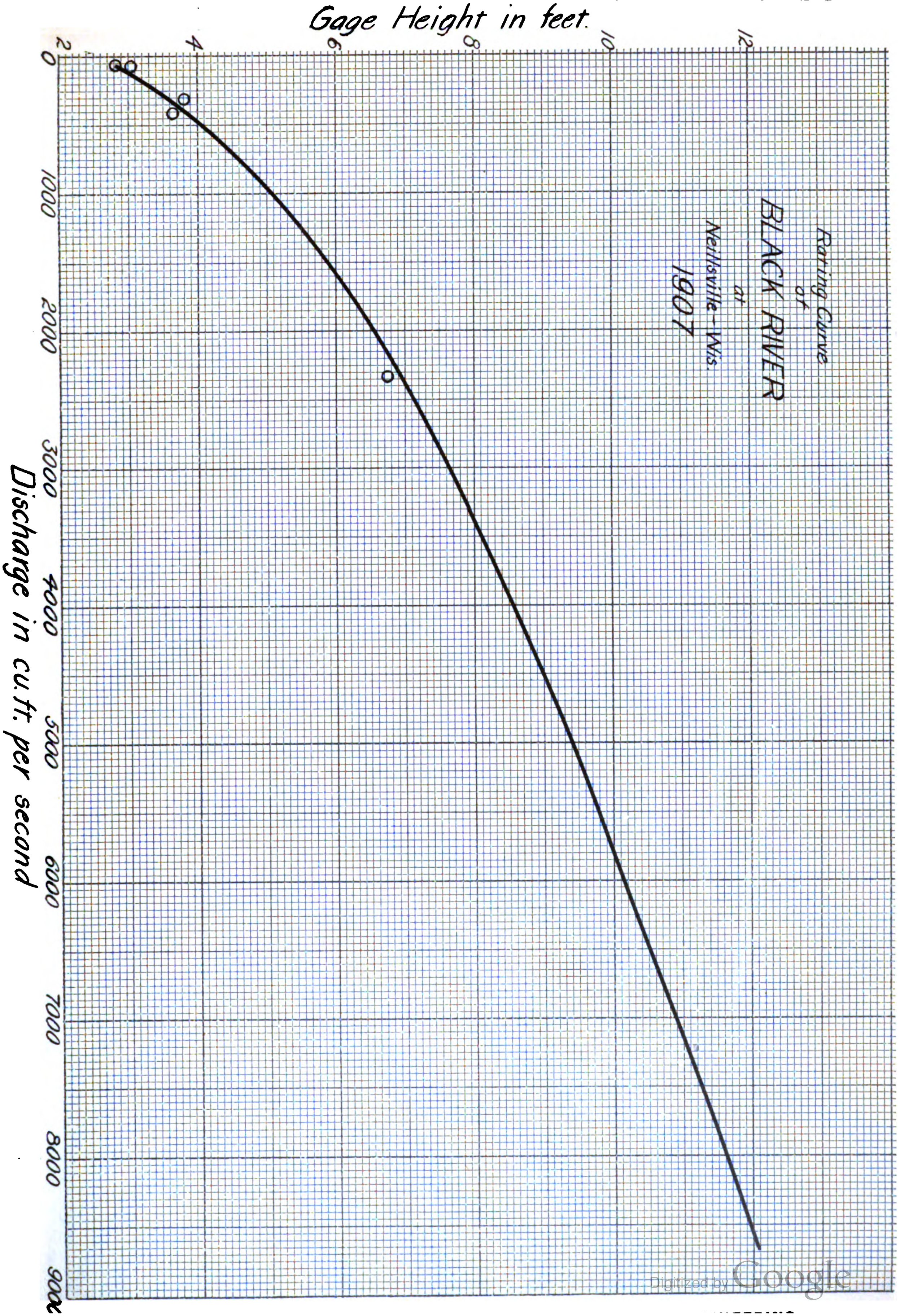
Vertical lines are drawn at these points and intersect the efficiency, horse power and discharge curves. Taking the points of intersection and reducing the values for the various heads, curves between horse power and efficiency were platted.

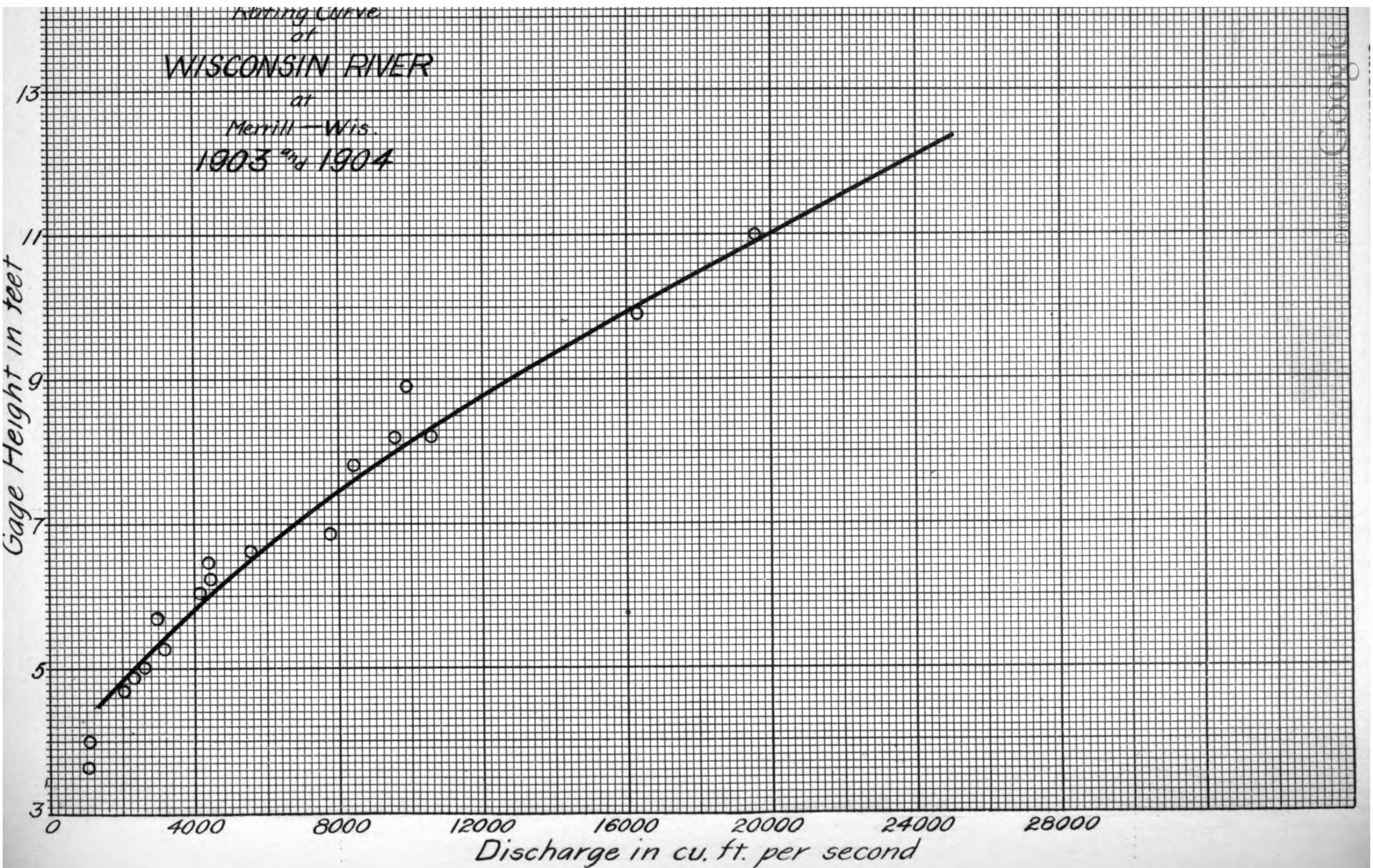
Conclusions

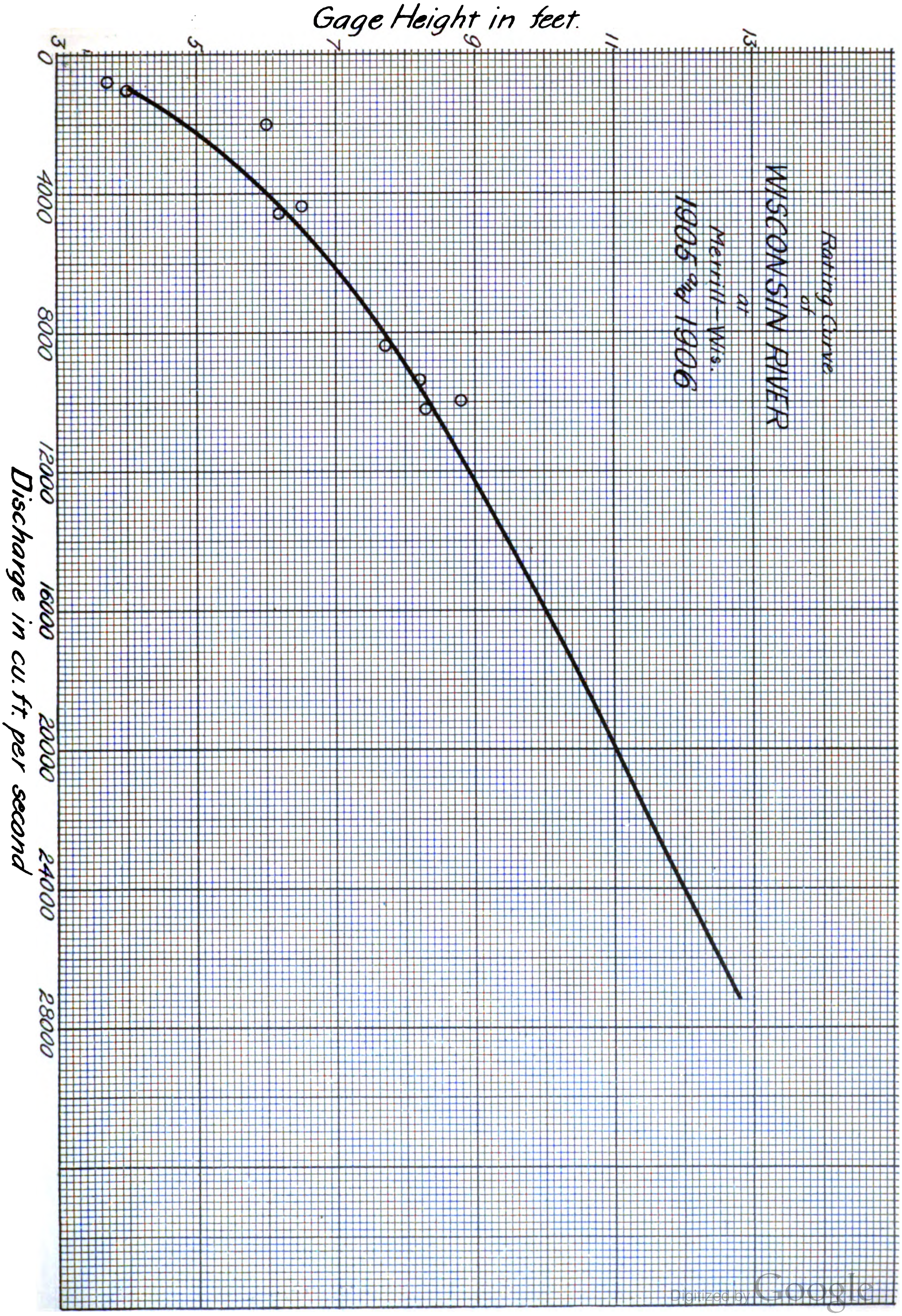
After a careful investigation of all the factors relative to the development of the power project in question, we are led to the decision that the Black River will deliver 2500 continuous horse power and that this amount of power will be at all times available.


Gage Height in feet.
3
5
7
9
11
13
Discharge in cu.ft. per second
0
2000
4000
6000
8000
10000
12000
14000
16000
Rating Curve
of
BLACK RIVER
at
Melrose — Wis.
1903

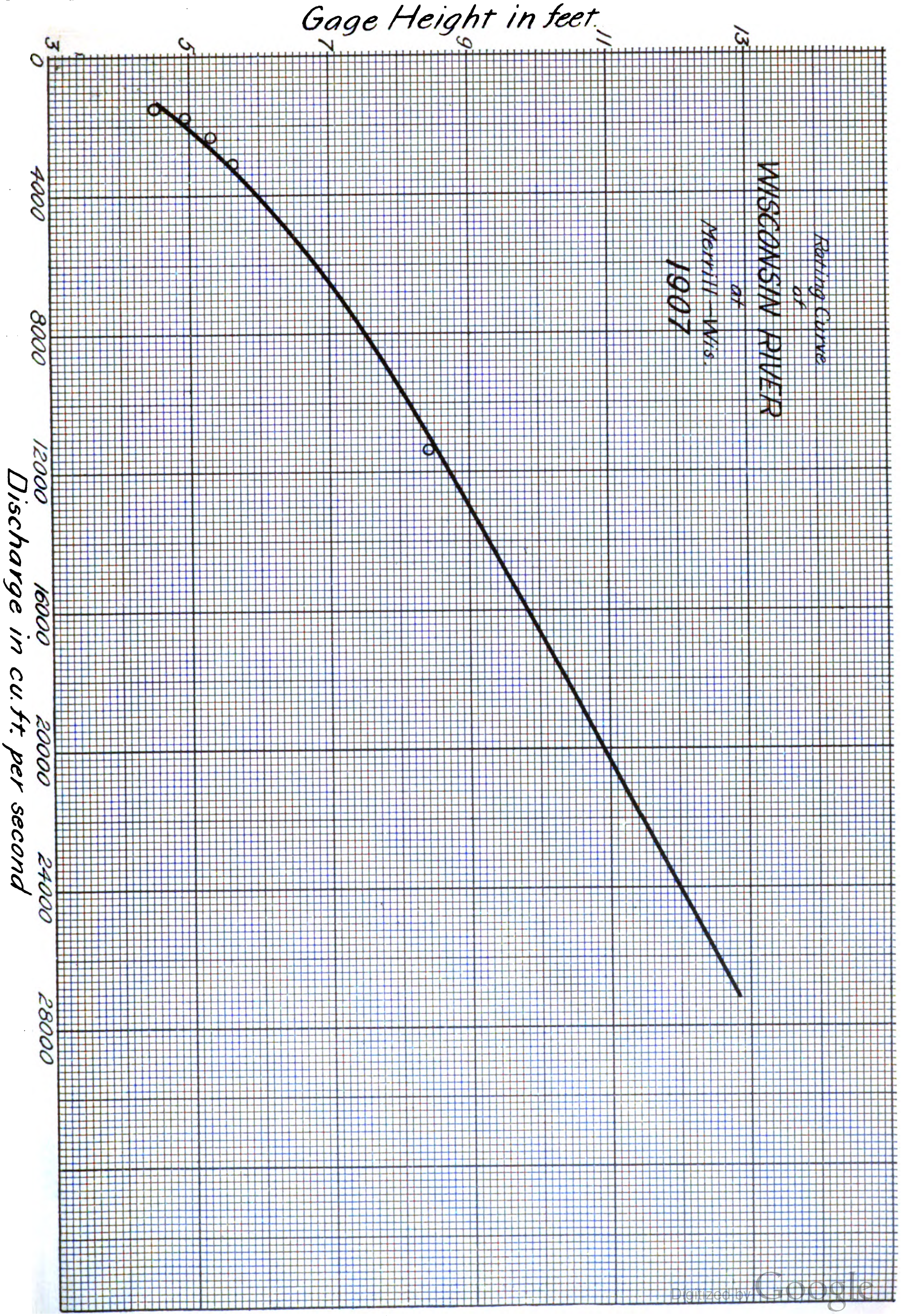

Gage Height in feet.
2
4
6
8
10
12
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Discharge in cu. ft. per second
of
BLACK RIVER
at
Neillsville-Wis.
1905 and 1906

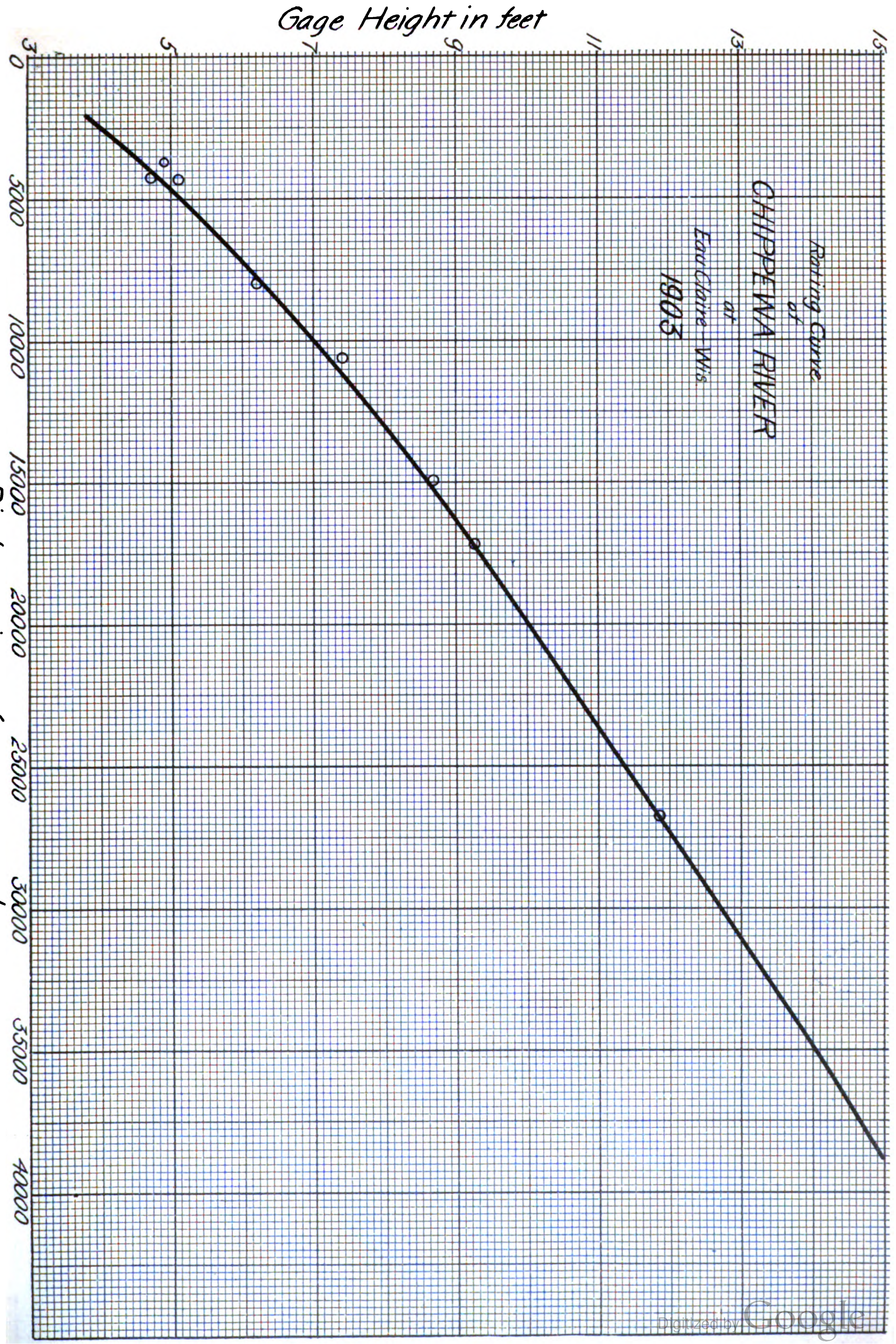

Gage Height in feet.
2
4
6
8
10
12
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Discharge in cu.ft. per second
Rating Curve
of
BLACK RIVER
at
Neillsville-Wis.
1907


Rating Curve
of
WISCONSIN RIVER
at
Merrill — Wis.
1903 and 1904
Gage Height in feet
3
5
7
9
11
13
0
4000
8000
12000
16000
20000
24000
28000
Discharge in cu. ft. per second

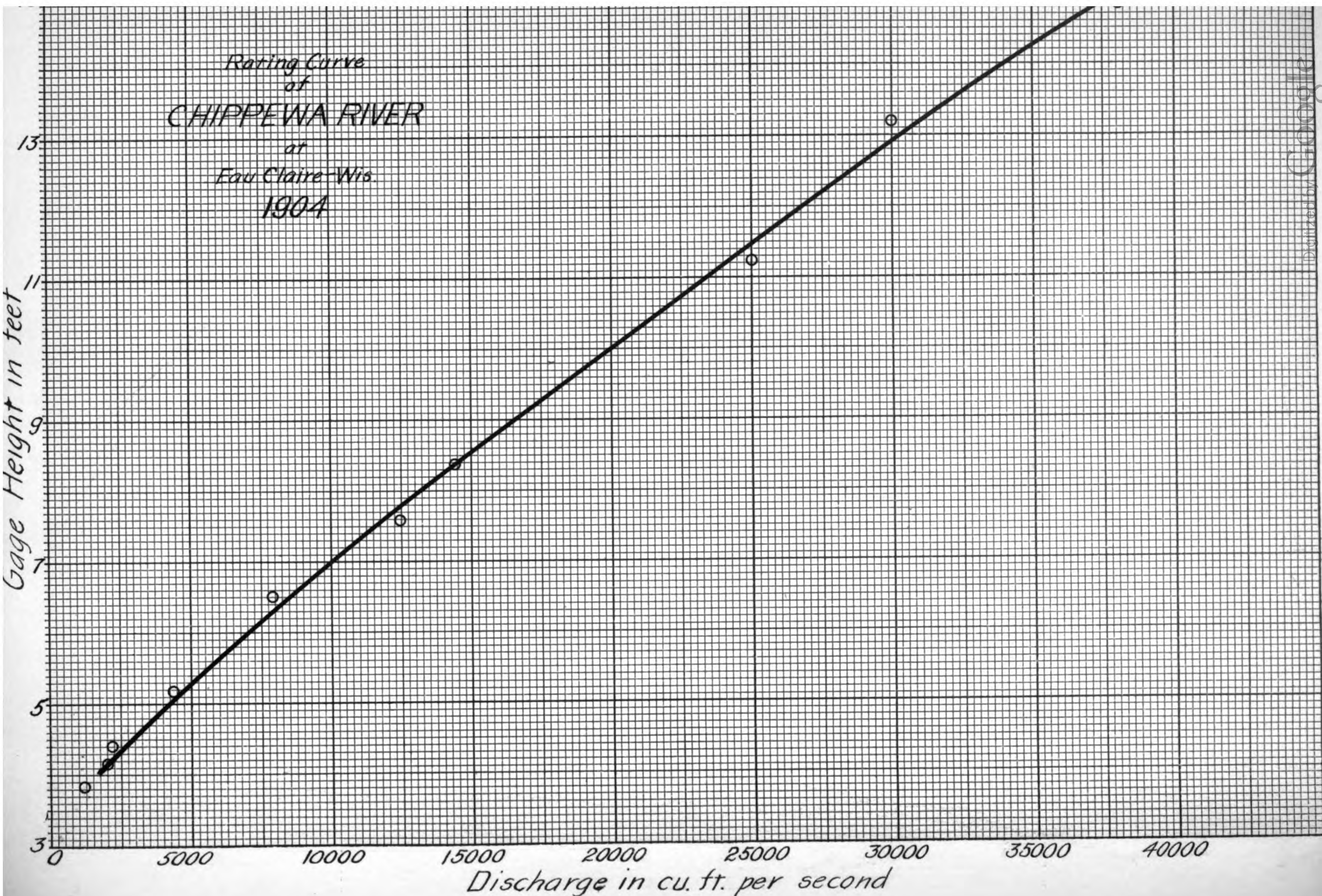


Gage Height in feet.
3
5
7
9
11
13
0
4000
8000
12000
16000
20000
24000
28000
Discharge in cu.ft. per second
Rating Curve
of
WISCONSIN RIVER
at
Merrill–Wis.
1905 and 1906

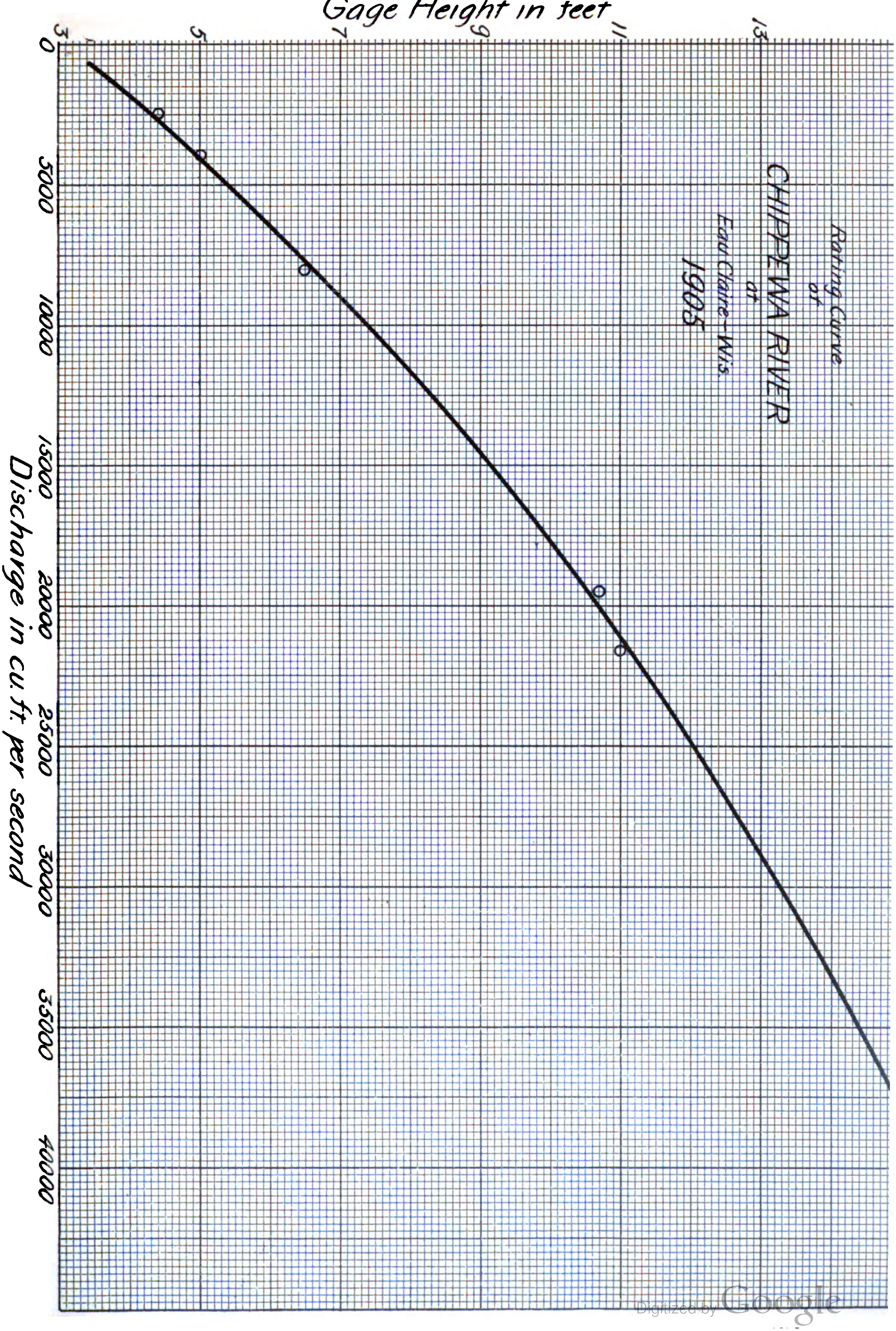

Gage Height in feet.
3
5
7
9
11
13
0
4000
8000
12000
16000
20000
24000
28000
Discharge in cu.ft. per second
Rating Curve of WISCONSIN RIVER at Merrill—Wis. 1907

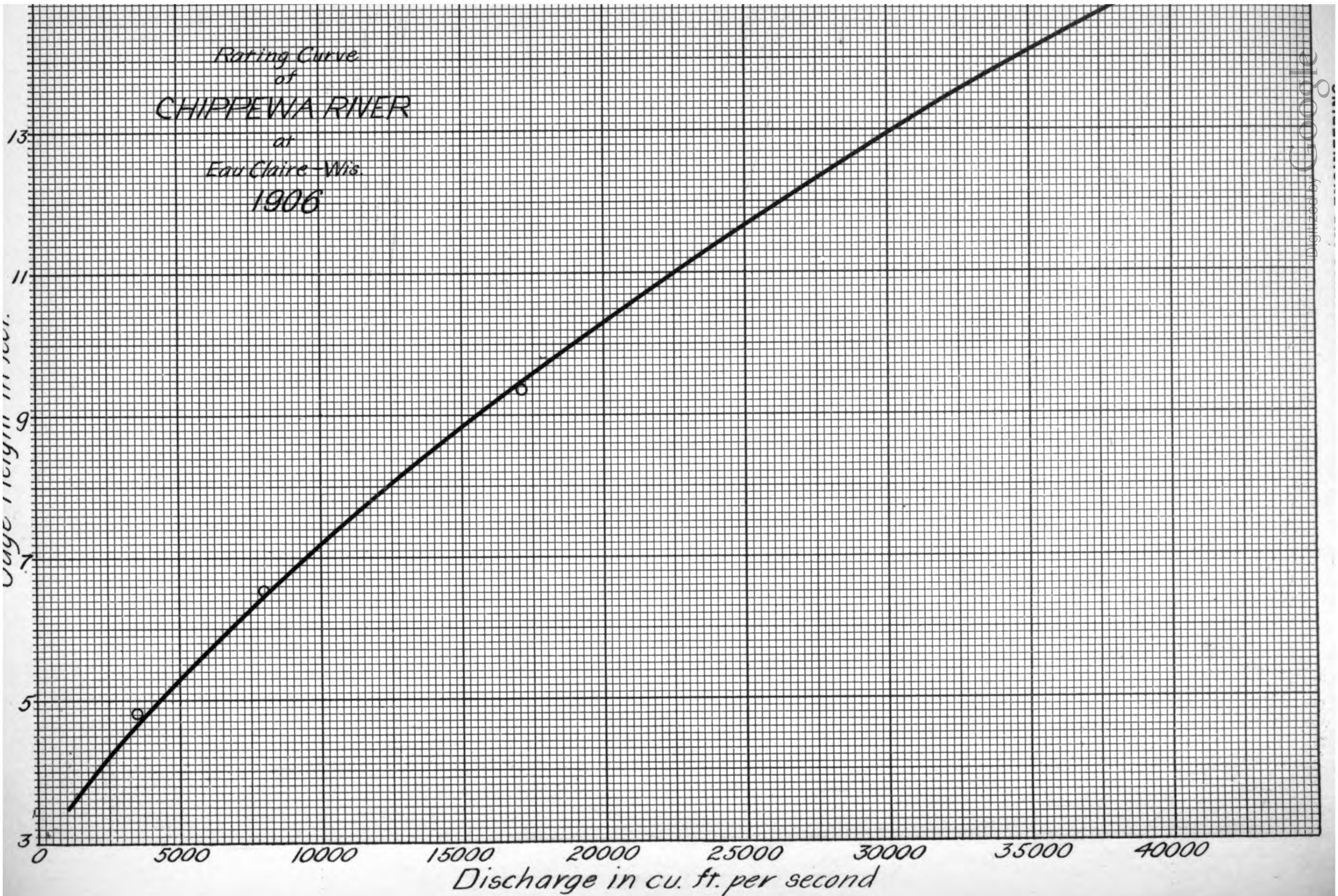


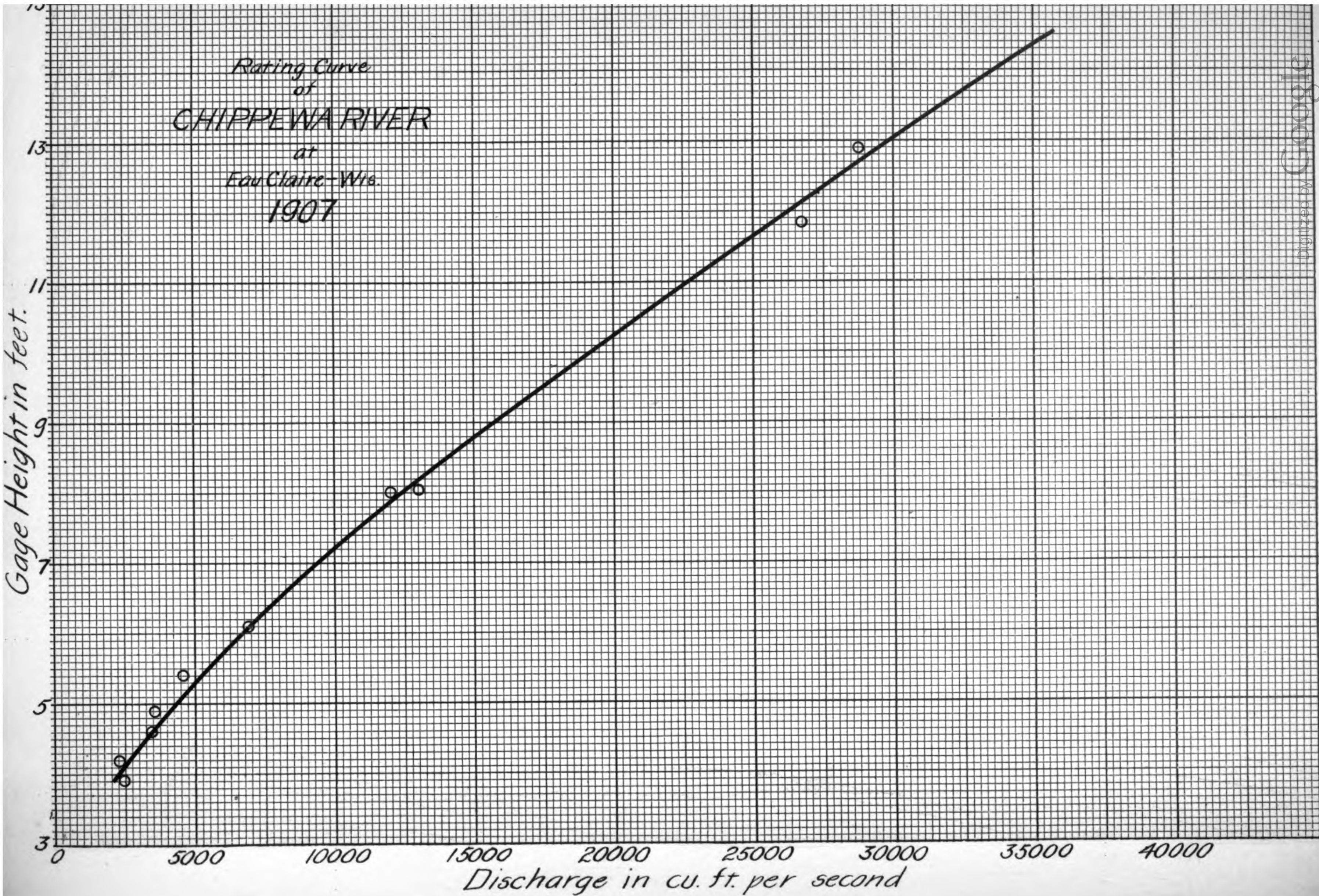
Gage Height in feet
3
5
7
9
11
13
15
0
5000
10000
15000
20000
25000
30000
35000
40000
Discharge in cu.ft. per second
Rating Curve
of
CHIPPEWA RIVER
at
Eau Claire – Wis
1903

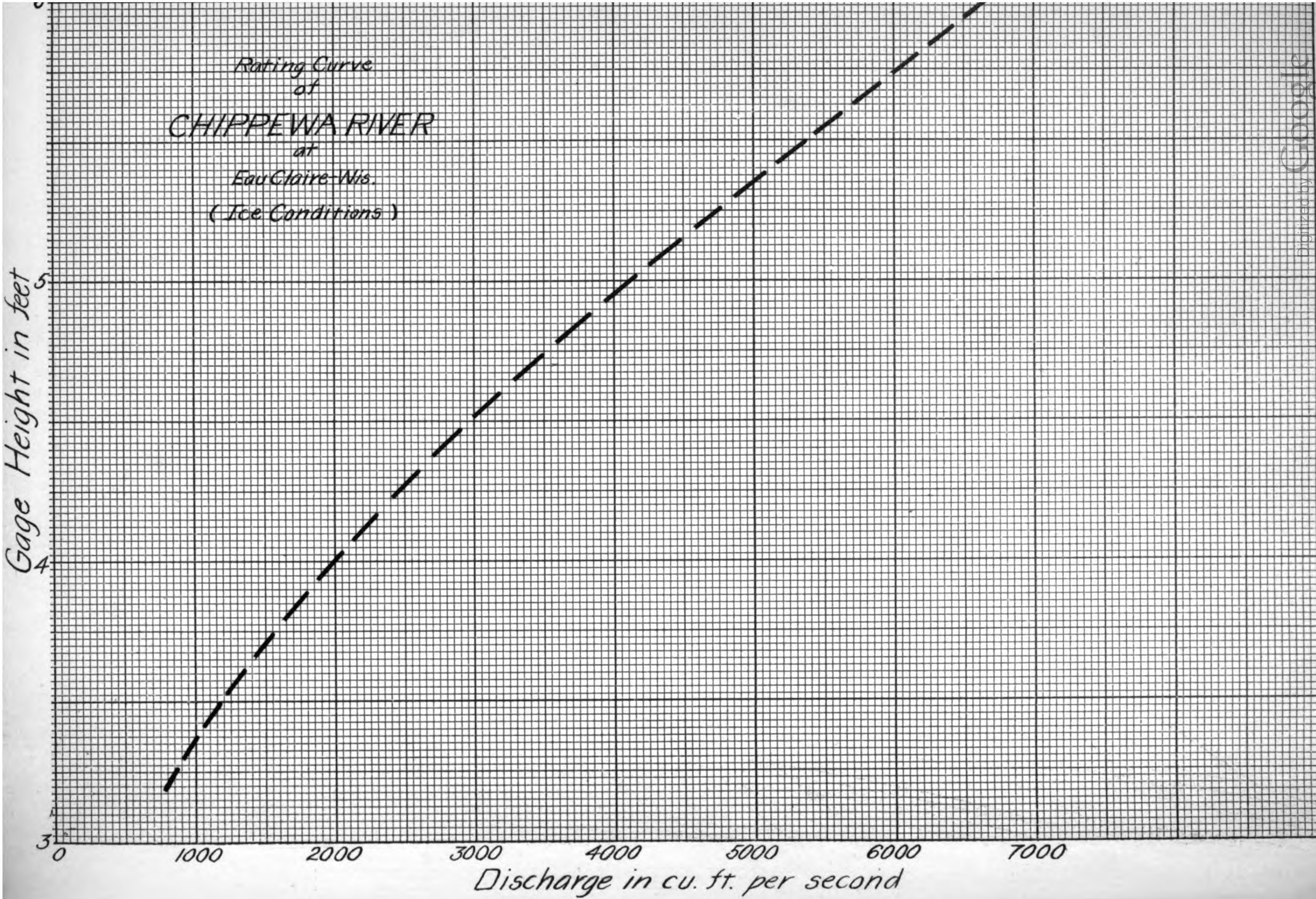


Rating Curve
of
CHIPPEWA RIVER
at
Eau Claire-Wis.
1904
Gage Height in feet
3
5
7
9
11
13
0
5000
10000
15000
20000
25000
30000
35000
40000
Discharge in cu. ft. per second

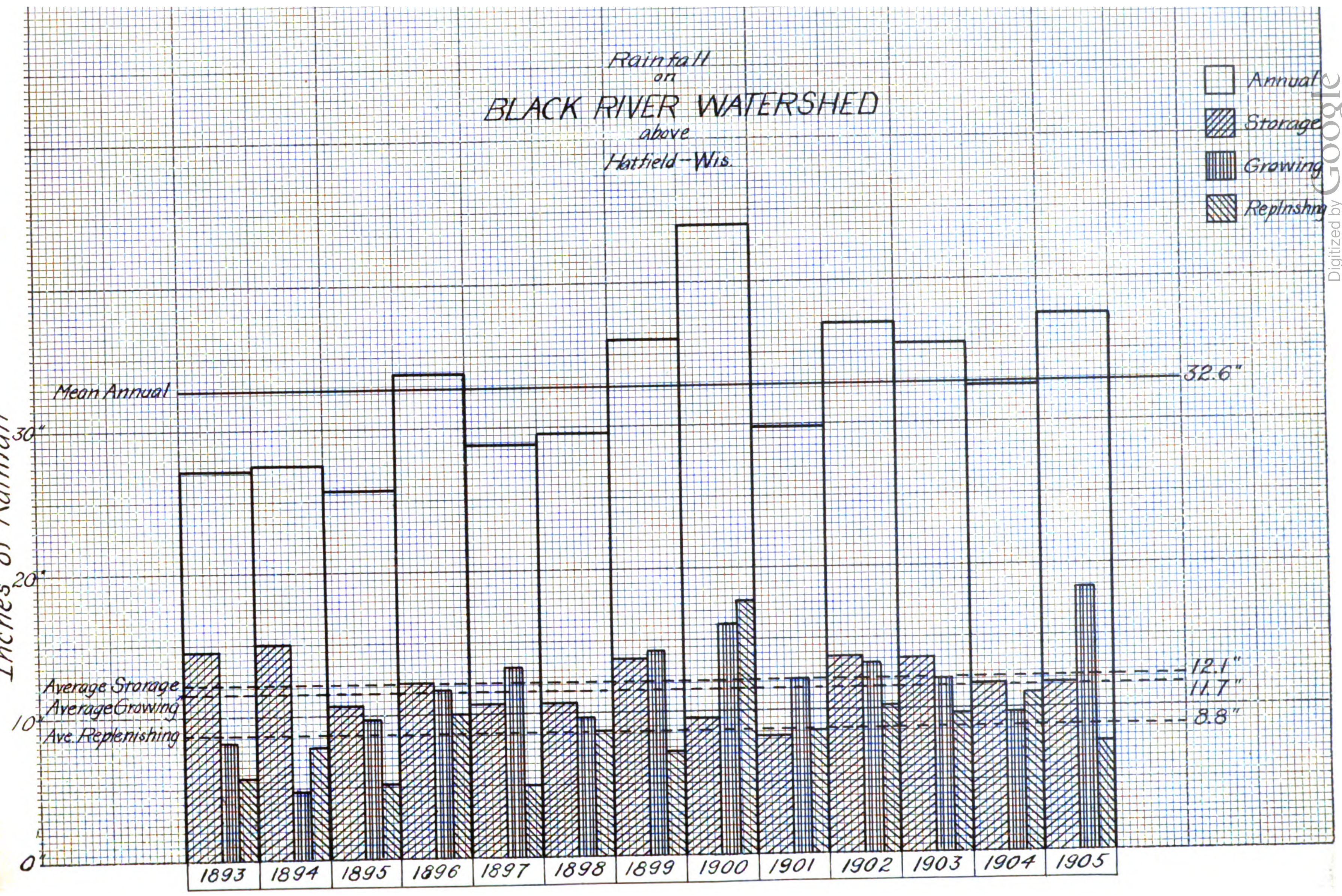

Gage Height in feet
3
5
7
9
11
13
0
5000
10000
15000
20000
25000
30000
35000
40000
Discharge in cu.ft. per second
Rating Curve
of
CHIPPEWA RIVER
at
Eau Claire-Wis
1905


Rating Curve
of
CHIPPEWA RIVER
at
Eau Claire - Wis.
1906
3
5
7
9
11
13
0
5000
10000
15000
20000
25000
30000
35000
40000
Discharge in cu. ft. per second

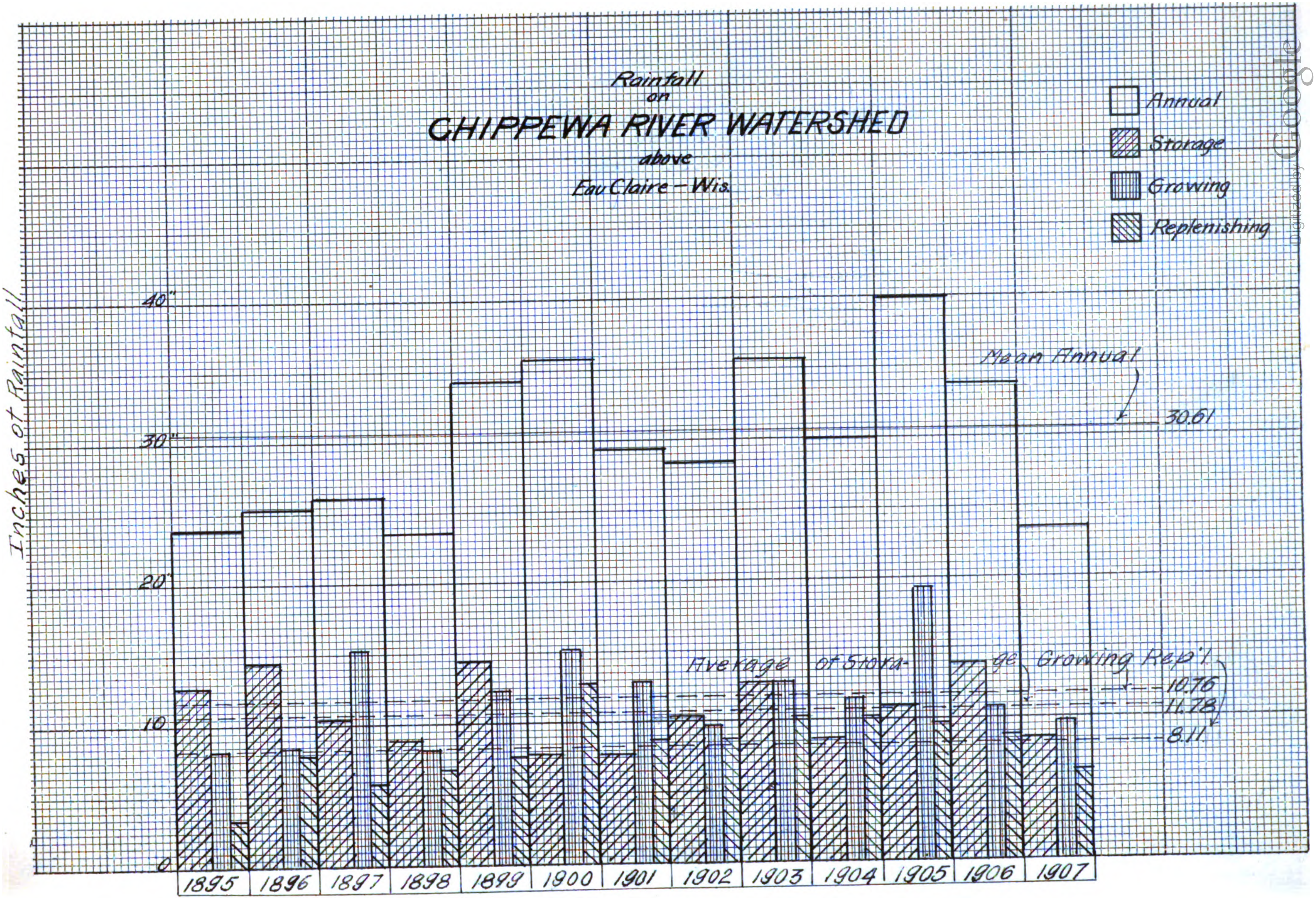

Rating Curve
of
CHIPPEWA RIVER
at
Eau Claire-Wis.
1907
Gage Height in feet.
3
5
7
9
11
13
0
5000
10000
15000
20000
25000
30000
35000
40000
Discharge in cu. ft. per second

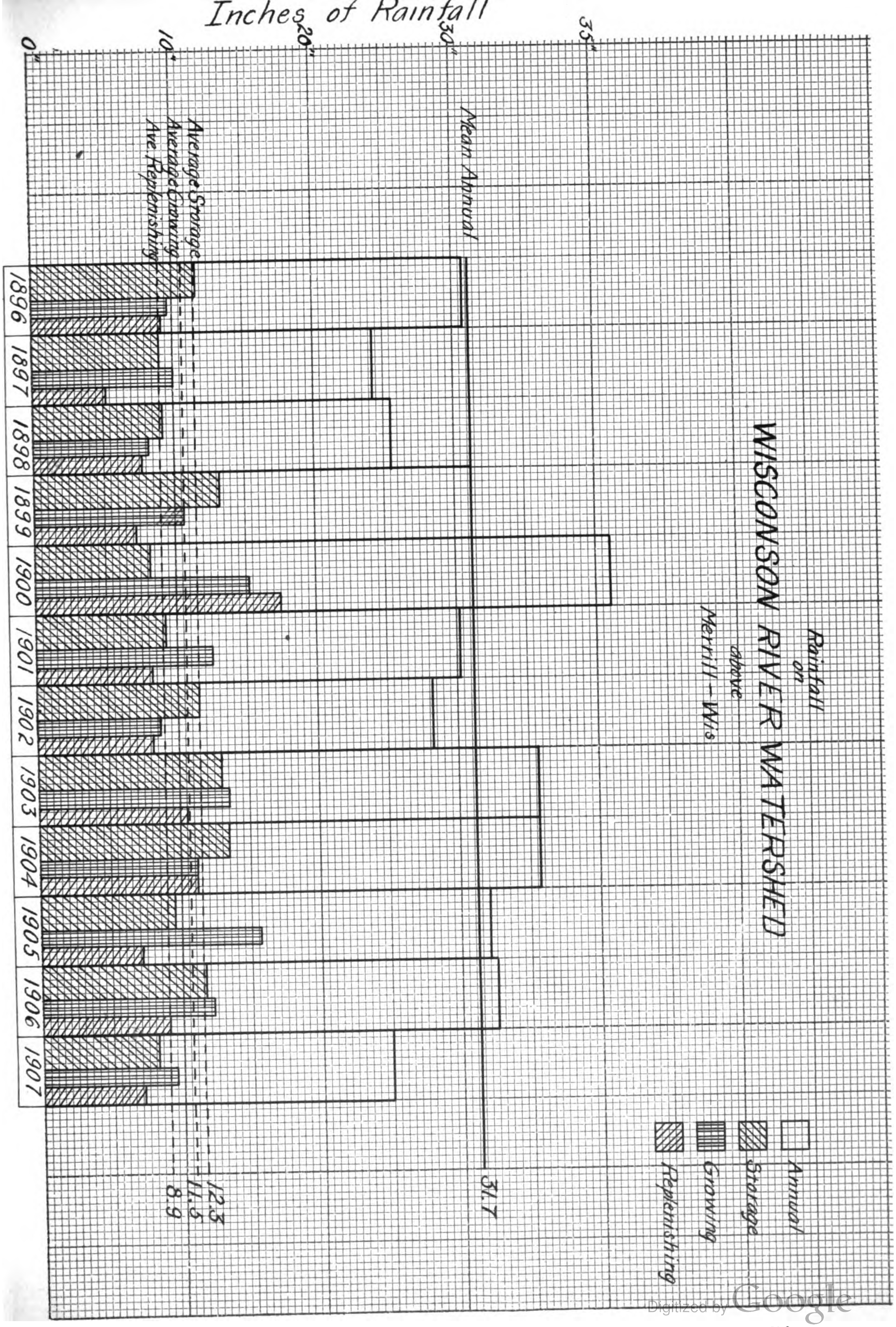


Rating Curve
of
CHIPPEWA RIVER
at
Eau Claire-Wis.
(Ice Conditions)
Gage Height in feet
3
4
5
0
1000
2000
3000
4000
5000
6000
7000
Discharge in cu. ft. per second

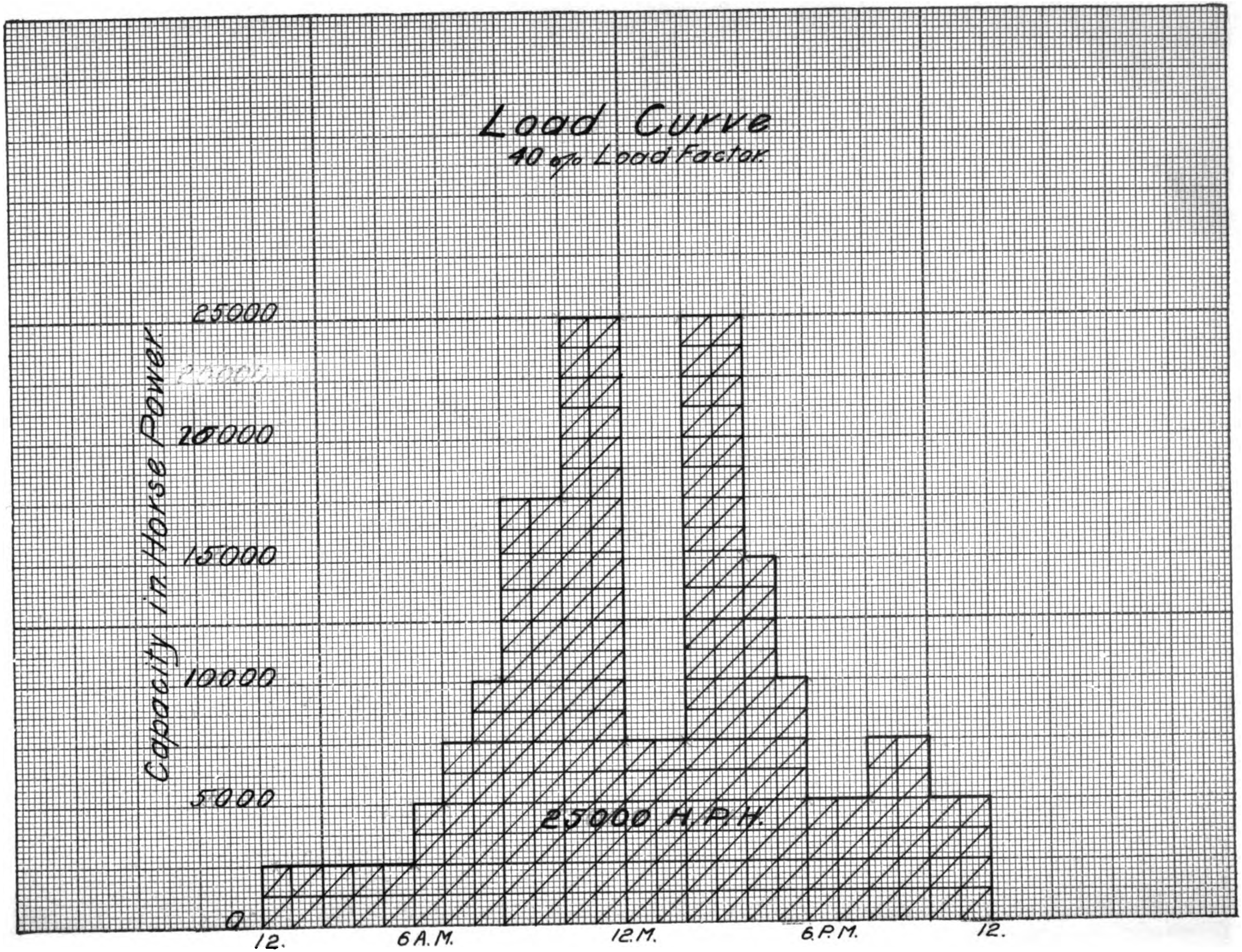


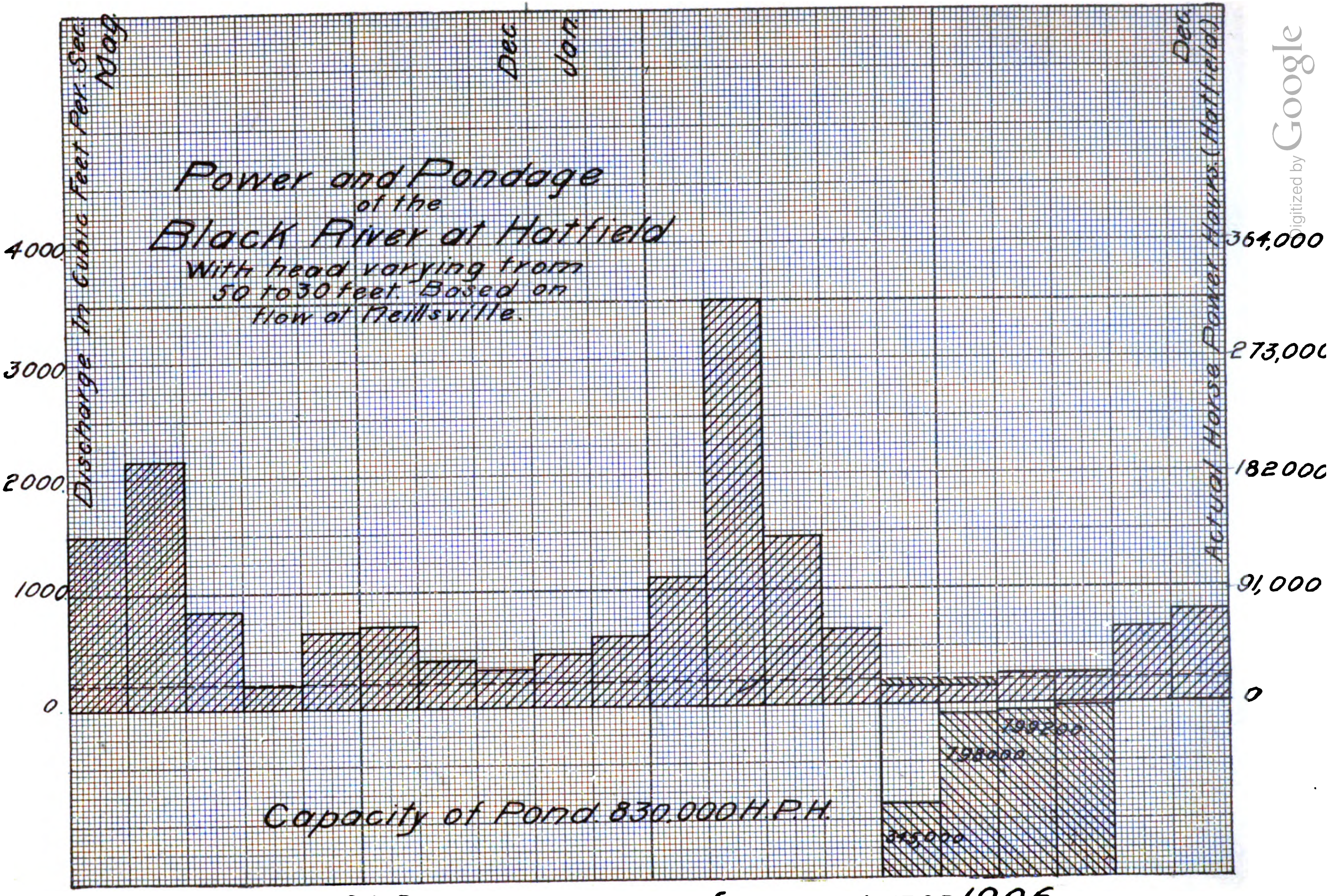
UNIVERSITY OF WISCONSIN. COLLEGE OF MECHANICS AND ENGINEERING


Rainfall
on
CHIPPEWA RIVER WATERSHED
above
Eau Claire - Wis.
Annual
Storage
Growing
Replenishing
Inches of Rainfall
40"
30"
20"
10
0
Mean Annual
30.61
Average of Storage
Growing Rep'l.
10.76
11.78
8.11
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907

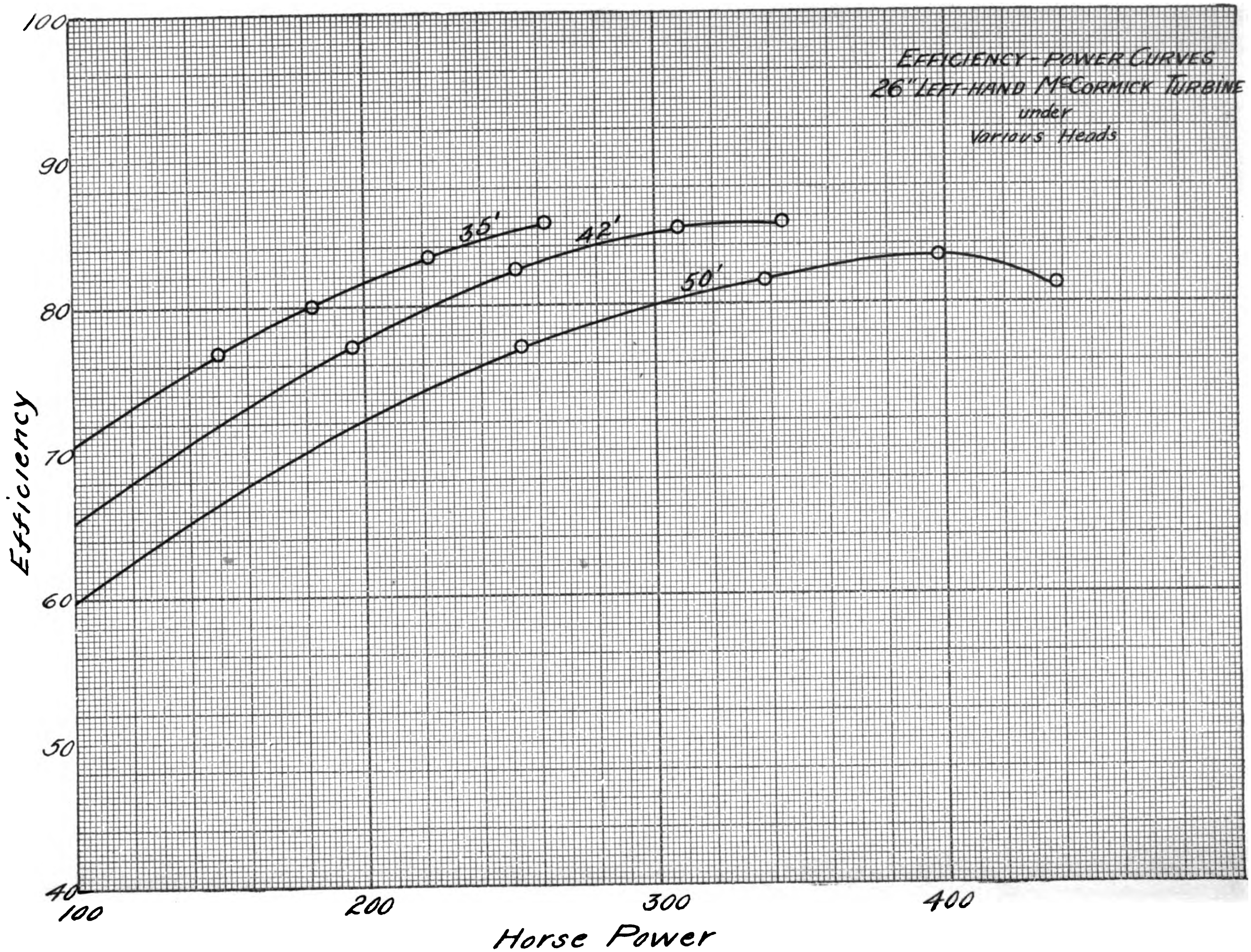


Inches of Rainfall
0"
10"
20"
30"
35"
Rainfall
on
WISCONSON RIVER WATERSHED
above
Merrill - Wis
Mean Annual
Average Storage
Average Growing
Ave Replenishing
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
31.7
12.3
11.5
8.9
Annual
Storage
Growing
Replenishing

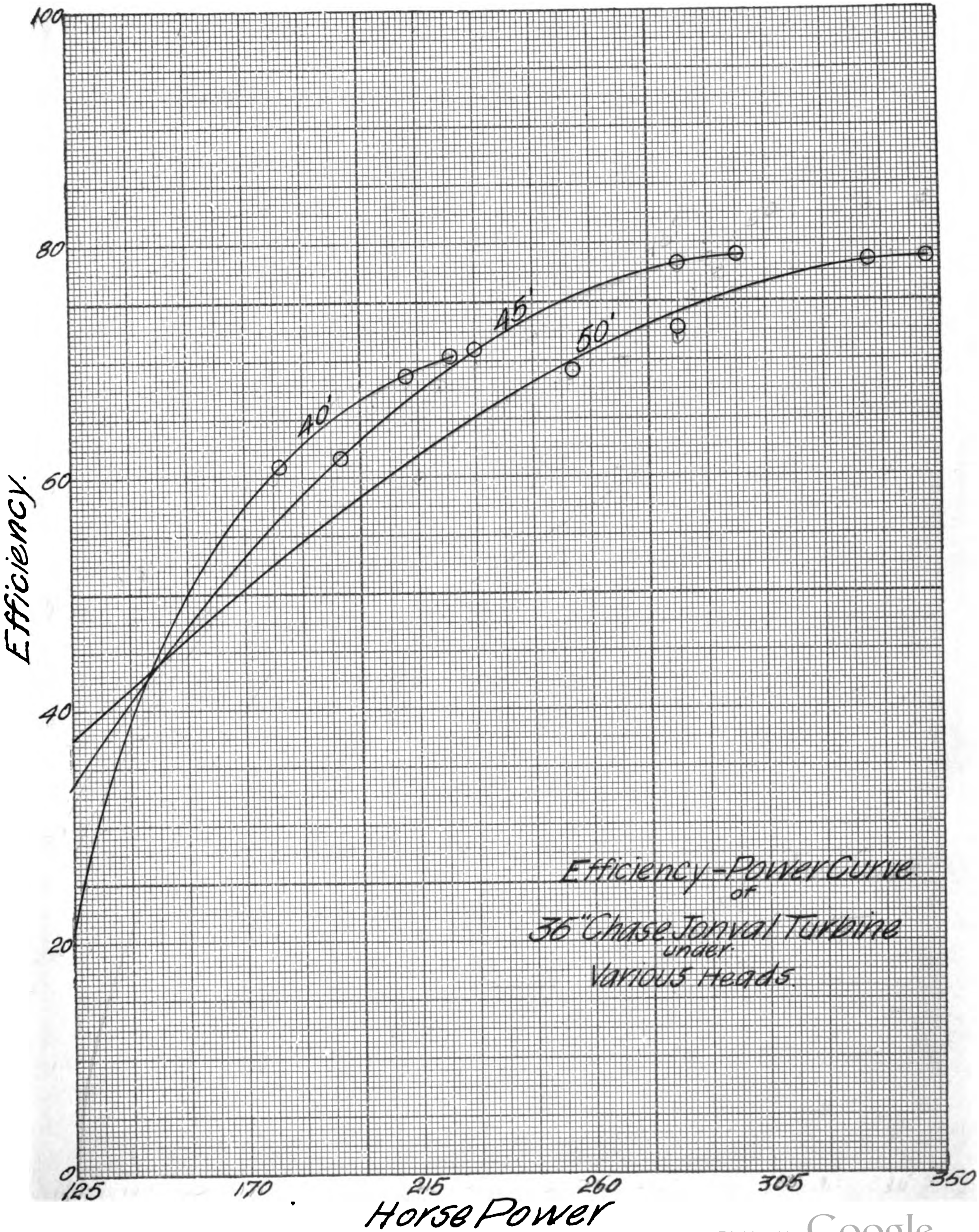

Load Curve
40 % Load Factor.
Capacity in Horse Power.
25000
20000
15000
10000
5000
0
25000 H.P.H.
12.
6 A.M.
12 M.
6 P.M.
12.



1905. Drainage Areas {Neillsville 1325. / Hatfield 800.} 1906.



EFFICIENCY-POWER CURVES
26" LEFT-HAND McCORMICK TURBINE
under
Various Heads
35'
42'
50'
100
90
80
70
60
50
40
Efficiency
100
200
300
400
Horse Power



100
80
60
40
20
0
Efficiency.
125
170
215
260
305
350
Horse Power
40'
45'
50'
Efficiency-Power Curve
of
36" Chase Jonval Turbine
under
Various Heads.

APPROVED BY Daniel W Mead

June 7th 1909